

ANNUAL PROGRESS REPORT ON

ONR Grant No. N00014-90-J-1305 and Modification A0001

"Experimental Simulation and Diagnostics of High-Enthalpy Real-Gas Flows"

1990

A) Description of scientific research goals.

The very high flow speeds (up to 8 km/s) of transport to and from space through the earth's atmosphere are necessarily associated with very high temperatures (up to 10,000 K) in ground testing and research facilities. Such facilities therefore have to operate only for very short test times. Various techniques have been devised for generating a test flow of sufficient flow speed and density to simulate the thermal and kinetic processes of high temperature gasdynamics correctly. Of these, the shock tunnel and the expansion tube principle are the most successful, and in both cases the high enthalpy regime requires the driver gas to be heated transiently to high temperatures (up to 4,000 K). This can most conveniently be achieved by a piston compression. A number of piston driven shock tunnels exist, and a new one (T5) is nearing completion at GALCIT. It has been funded by the Joint Project Office (JPO) of the National Aerospace Plane (NASP) program through Rocketdyne Division of Rockwell International (approx. \$1.5 M) and Caltech (approx. \$1.5 M). It will be the first such facility in the USA.

Many new and only partially understood effects occur in the flows associated with the NASP. Dissociative nonequilibrium effects in the external flow, mixing and combustion processes in SCRAMJET engines and boundary layers in real-gas flows pose new problems that can presently not be solved by computational fluid dynamics (CFD) techniques. Key experimental data are needed to test and supply parameters for CFD methods.

The aim of the research funded by the above grant is to initiate research in this field with the longer term view of building up the capability and know-how needed for competence in this field. The specific initial efforts concentrate on

1. Mixing and combustion processes
2. Real-gas boundary layers.

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B) Significant results in the last year.

The progress of the facility construction has not been as rapid as had been anticipated in the proposal. A number of unforeseen problems arose. Specifically, one portion of the shock tube had to be remade twice, because cracks developed during heat treatment after forging and rough machining the part. These cracks were discovered by the ultrasonic testing specified for the quality assurance. This and a number of machining errors on different parts have caused a total of 9 months delay. The facility is now expected to become operational in October 1990.

Our activities have therefore been concentrated on the following main tasks.

1. Design and purchase of parts for the optical system (Differential interferometry).
2. Design and purchase of the data acquisition and control system.
3. Write computer program for calculating the free piston shock tunnel performance.

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4. Design and begin construction of a new type of hydrogen injection system
5. Make a feasibility study of a new method of heat transfer measurement.

Task 1 Almost all the parts have been bought. A temporary setup using borrowed parts for those that are missing, has been tested.

Task 2 The data control system, which consists of a workstation, coupled with a data acquisition system for 18 pressure transducers, 10 amplified channels, 40 data channels and 3 time intervals, has been purchased. The workstation has been programmed for normal operation of the facility and partially programmed for data reduction.

Task 3 The computer program which consists of an unsteady method of characteristics program with area change and real-gas effects (>3000 FORTRAN lines) has been written and tested. It has been applied to computations of T4, an existing free-piston shock tunnel at the University of Queensland, Australia, and compared with experimental results obtained in T4.

Task 4 The design of the new hydrogen injection system is based on a small combustion driven shock tunnel with hydrogen as test gas. The operation of the small shock tunnel has to be synchronized with the operation of T5. This poses the problem of triggering the rupture of the main diaphragm of the injection shock tunnel from as late as possible an event in T5 and after combustion in the driver gas of the injection tunnel. Preliminary experiments led to a new technique for triggering the rupture. The design of the device is complete and purchase of gauges, valves and vacuum equipment as well as machining of parts are in progress.

Task 5 A serious problem arising in heat transfer measurement at high enthalpy by thin film resistance thermometry is that the electrical noise arising because the gas is often partially ionized deteriorates the signal-to-noise ratio excessively. An alternative method using newly available infra-red fiber optics and sensors was therefore investigated and shown to be feasible with the most modern devices developed recently at Caltech and elsewhere. A pilot experiment is being designed, which is expected to demonstrate the effectiveness of this new method.

C) Publications.

During the year the following publications were produced:

- [1] Hornung, H. & Sturtevant, B. "Challenges for high-enthalpy gasdynamics research during the 1990's: Plans for the GALCIT T5 Laboratory," Report No. FM90-1, Graduate Aeronautical Laboratories, California Institute of Technology, Pasadena, CA. (Attached)
- [2] Germain, Patrick "Three Samples of Inviscid Supersonic Reacting Nozzle Flow Calculation using SURF," Report No. FM90-2, Graduate Aeronautical Laboratories, California Institute of Technology, Pasadena, CA. (Attached)
- [3] Hornung, Hans G. and Belanger, Jacques "Role and Techniques of Ground Testing for Simulation of Flows Up to Orbital Speed," presented at the AIAA 16th Aerodynamic Ground Testing Conference, Seattle, WA, June 18-20, 1990, AIAA 90-1377. (Attached)

D) Plans for next year's research

Developments during the current year have caused Rocketdyne to abandon the completion of the large free-piston shock tunnel known as RHYFL. Even if an alternative group takes over the parts and completes the facility, the most optimistic estimates put first operation at three years from now. This means that the time for which the modern instrumentation that has already been built for RHYFL will be available for tests in T5 is much longer than was expected at the time of the proposal for this Grant.

A consequence is that we expect to be able to apply much more sophisticated instrumentation, including planar laser induced fluorescence (PLIF), and time-resolved mass spectrometry to our own experiments for an extended period. First experiments with the Rocketdyne instrumentation on the aims of this research will be performed on the investigation of turbulent mixing and combustion with hydrogen injection and on the investigation of turbulent boundary layer structure on a slender cone.

The new method of heat transfer measurement will be tested in a preliminary experiment and in calibration experiments. If successful, it will then be redesigned and incorporated in simple models for measuring heat-transfer distributions in external flows in conjunction with other techniques for measuring boundary layer structure.

Funding under this grant has been provided for the initiation of research in the direction towards building competence in this field. The start that has been made during the past year has certainly provided us with an excellent preparation for the experiments that are planned for FY91.



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